Understanding the Effects of Water-Column Variability on Very-High-Frequency Acoustic Propagation in Support of High-Data-Rate Acoustic Communication Applications

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LONG-TERM GOALS

To understand the impact, and relative importance, of different physical processes on very-high-frequency (100 kHz – 1 MHz) acoustic propagation in different environments and in support of high-data-rate underwater acoustic communication systems. To develop and test an integrated very-high-frequency acoustic communication system for use on autonomous platforms.

OBJECTIVES

The first and primary objective is to understand the impact of high-stratification, small-scale water-column temperature and salinity fluctuations, and suspended sediment loads, on very-high-frequency (VHF) acoustic propagation. Particular attention will be given to the potentially strong frequency dependent scattering mechanisms associated to these different physical processes. This objective will be achieved by completing the analysis of acoustic scattering and propagation data collected in a highly salt-stratified estuary in December 2012, an experiment funded by the ONR Ocean Acoustics Program.

A secondary, related, objective involves the development of an integrated, VHF broadband acoustic transmission and reception system that is capable of both taking acoustic scattering measurements within the water column and upper ocean boundary layer and simultaneously implementing a versatile VHF acoustic communications capability. This objective will be achieved through the continued development and testing of a VHF (spanning 100 kHz – 1.25 MHz), broad-bandwidth, low-power, autonomous, compact, multi-channel, acoustic communication system (seed funding for the hardware provided by WHOI), appropriate for use on autonomous platforms, such as unmanned underwater vehicles.

APPROACH

There has been increased interest recently in very-high-frequency (VHF > 100 kHz), broad-bandwidth, high-data-rate (hundreds of kbps), underwater acoustic communications to complement optical

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communication systems. Recent developments in underwater optical communications techniques offer solutions at very short range (< 100 meters) in very clear, generally deep, water and away from sunlight (i.e., restricted to night time operations). In contrast, ultra wideband VHF acoustic systems offer the potential for systems whose bandwidth and achievable range are scalable by shifting in frequency to match application requirements and which are not sensitive to daylight contamination or water column turbidity. Thus, VHF acoustic communication systems, operating over spatial ranges spanning 50-200 m, can be more appropriate than optical communication systems for covert operations, while simultaneously less susceptible to ambient light and environmental factors such as increased water-column variability and the presence of high concentrations of scatterers, typical in shallow water environments. In fact, there are a wide range of physical processes that impact underwater acoustic communication systems and the relative importance of these physical processes are different at different frequencies and in different environments. In order to improve algorithm design for VHF acoustic communication systems it is necessary to first develop very-high-frequency propagation and scattering physics models that include the appropriate physical processes and their associated spatial and temporal scales of variability.

The first and primary focus of this project is on the analysis of very-high-frequency (120 kHz) acoustic scattering and propagation data collected in a highly salt-stratified estuary in December 2012, an experiment funded by the ONR Ocean Acoustics Program [1]. These data will contribute to our understanding of the influence of high-stratification, water-column temperature and salinity fluctuations, and the presence of suspended sediments on VHF acoustic propagation and scattering. MIT-WHOI Joint Program graduate student Jon Fincke, funded through an NDSEG Fellowship, has started part of his graduate training in acoustics by working on the acoustic scintillation data collected in the Connecticut River Estuary. As an incidental benefit of this increased understanding of the propagation and scattering physics for the purposes of improving VHF acoustic communications, comes the improved ability for remote sensing of the path-averaged statistical structure and motion of the intervening flow, with possible advances for remotely characterizing turbulence, microstructure, and advection.

The second, related, focus of this project involves the continued development and testing, in collaboration with Jim Preisig (WHOI) and Grant Deane (Scripps), of a broad-bandwidth (capable of operating at frequencies spanning 100 kHz – 1.25 MHz), low-power, autonomous, compact, multi-channel, VHF acoustic communication system appropriate for use on autonomous platforms, such as unmanned underwater vehicles. The ability to utilize untethered instruments greatly simplifies deployment, particularly in challenging and inaccessible environments, and opens up a wide range of applications enabled by the deployment on mobile platforms, moorings, etc. This technology is not widely available in off-the-shelf devices, and available off-the-shelf VHF broadband systems are not deployable from small, remotely powered and/or untethered autonomous platforms due to power and payload constraints. While in the past the physical limitations of transducer technology have made the use of integrated devices that can span VHF frequencies difficult, the development of piezoelectric composite transducer technology [2,3] has made small and very broadband transducers available in compact, integrated packages containing multiple transmit/receive elements. A system such as the one we are developing, which exploits emerging technological advances in transducer technologies, atomic clocks, and low-powered computing technology for the mobile computing market, could be instrumental for advancing the goals of high-data-rate acoustic communications research [4].

WORK COMPLETED

Analysis of scintillation data

A detailed description of scintillation experiment conducted in the Connecticut River estuary in December 2012 can be found in [1]. In general terms, acoustic scintillation refers to the accumulation of the effects of the continuously evolving amplitude and phase of the acoustic waves as they propagate through a fluctuating medium. Mean fluid motion, turbulent velocity fluctuations, and temperature and salinity fluctuations contribute to the forward scattering and thus to the variability in the effective refractive index of the fluid. The acoustic propagation measurements involved two identical, 0.75 m^2, 4-element square arrays centered 3 m above the bottom (mean depth at low tide approximately 6 m, with approximately 1 m tidal excursions), mounted on tripods separated by a path length of approximately 40 m. All transducers were identical, with a relatively flat response over the frequency band from 80-120 kHz, and each with a 10 degree full-beamwidth at center frequency. Each transducer channel had both transmitting and receiving capabilities, allowing forward and reciprocal acoustic transmissions along 16 different paths.

In order to allow the propagation data to be understood and fully exploited, it is necessary to first extract time series of amplitude, time-of-arrival, and phase for all channels. Initial analyses completed prior to the start of this project involved the inference of the time-of-arrival structure throughout the duration of the experiment for one transmit/receive pair on each of the tripods. Since the start of this project, time series of amplitude and phase have been extracted for all combinations channels.

Development and testing of an integrated VHF acoustic system

The current system is designed around transducers with 500 kHz center-frequency, bandwidth of approximately 250-800 kHz, and incorporates one transmit and two receivers. However the system is designed to be fully modular and expandable (block-design of the current WHOI system is shown in Figure 1). The first version of the system has been recently (August 2014) bench tested for initial functionality, timeline consistent with the submitted proposal, and data collected from scattering from a pressure-release surface have been compared to data collected with existing laboratory hardware (detailed in [5]). The continued bench testing of the system design involves determining power-consumption, frequency-dependent bandwidth, dynamic range, signal and timing fidelity, noise floor limits, and other functionalities. Following the successful bench testing of all modalities, the system will be transitioned into an underwater housing, and then tested off the WHOI dock.

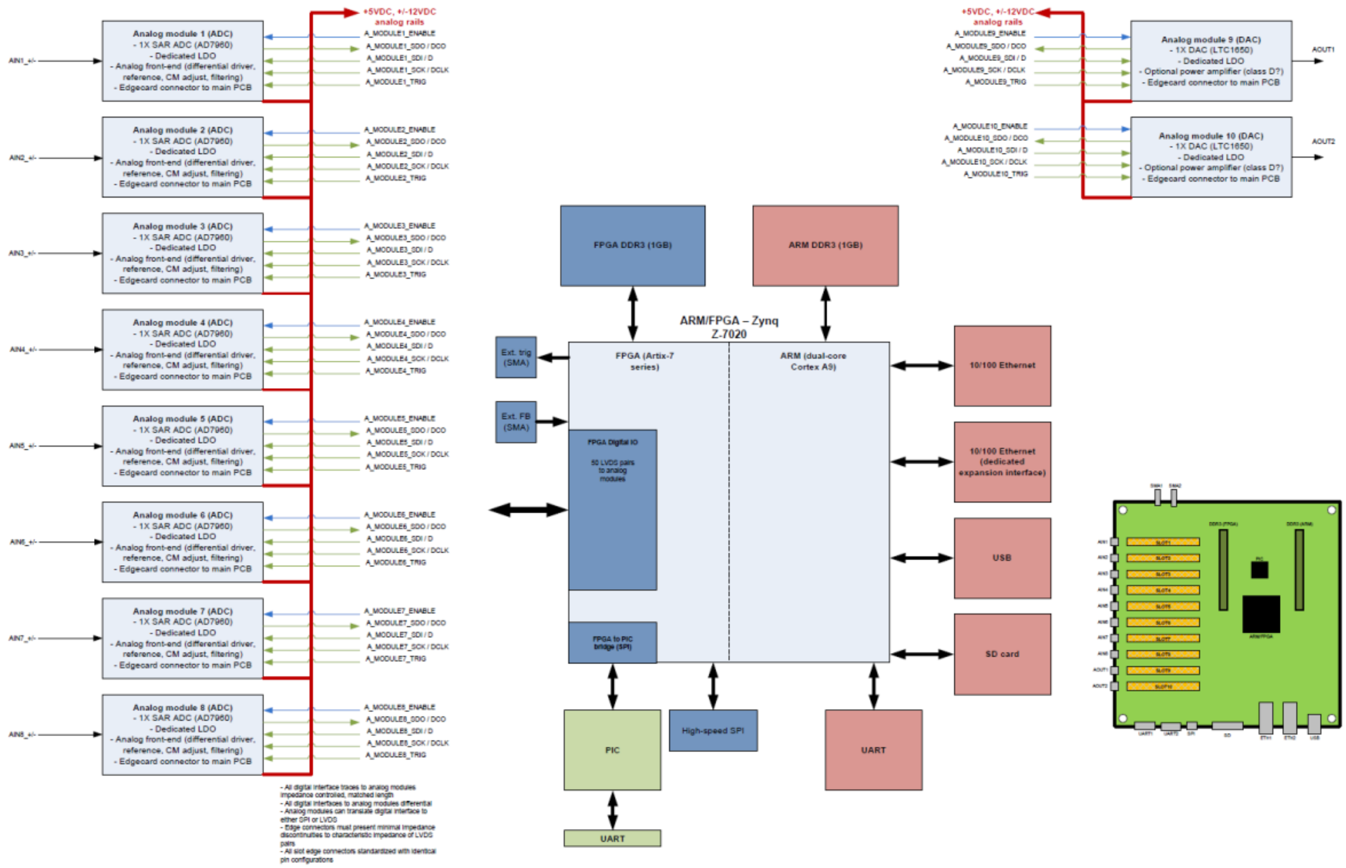

Figure 1. Block-design of the integrated VHF acoustic system currently being developed at WHOI.

RESULTS

This project is at its inception (funding received in May) and detailed results, modeling, and inferences will be forthcoming in the next year.

IMPACT/APPLICATIONS

Impact: Increased understanding of very-high-frequency acoustic propagation in shallow estuarine environments characterized by strong tidal flow, high shear, strong stratification and dissipation, increased water property variability, and times of high suspended sediment loads. Assessment of the potential importance of suspended sediment loads, velocity maxima, boundary layer turbulence, anisotropy, and 3-D structure of turbulence in determining very-high-frequency acoustic propagation. Deliverable: A tested, integrated VHF broadband acoustic communications system appropriate for use on autonomous platforms.

RELATED PROJECTS

Andone Lavery (co-PI Jim Preisig, and in collaboration with Grant Deane at Scripps) has been funded through an internal WHOI proposal for the hardware development of the very-high-frequency (100 kHz – 1.25 MHz), ultra-broadband, low-power, autonomous, acoustic communication system

appropriate for use on autonomous platforms, such as moorings or autonomous underwater vehicles. The development of this system is being pursued through the Instrument System Development Laboratory at WHOI. The primary WHOI engineers on the project are Micheil Boesel and Keith von der Heydt.

REFERENCES

[1] Final project report submitted to ONR Ocean Acoustics, entitled “High-frequency acoustic propagation in shallow, energetic, highly-slt-stratified environments,” PIs: Lavery and Farmer. Grant Number N00014-11-10058.

[2] Material Systems Inc., http://www.matsysinc.com/products/materials/.

[3] Nortec Piezo, http://www.nortek-as.com/en/news/transducer-uplift-nortek-piezo-joins-the-nortek-family.

[4] Recent SBIR: N132-138

[5] Lavery, A.C. and Ross, T. 2007. Acoustic scattering from double-diffusive microstructure. *J. Acoust. Soc. Am.*, **122**: 1449-1462.

HONORS/AWARDS/PRIZES

Andone C. Lavery, Woods Hole Oceanographic Institution, Acoustical Society of America Medwin Prize in Acoustical Oceanography, Acoustical Society of America.